

UNCLASSIFIED

AD 296 759

*Reproduced
by the*

**ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA**



UNCLASSIFIED

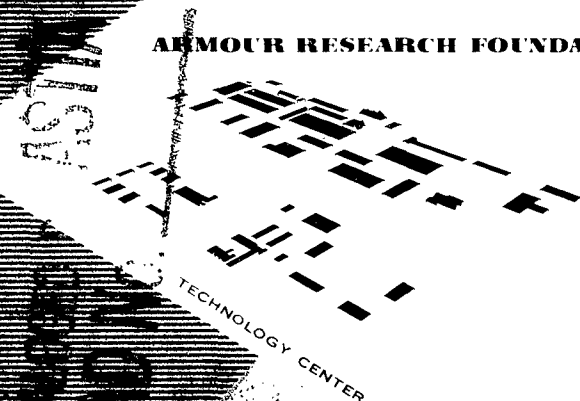
NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

63-2-4

296 759

ARF

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY



NO RESTRICTIONS FOR ASTIA DISTRIBUTION

ASTIA
RECEIVED
FEB 26 1963
ASTIA

PILOT EVALUATION OF VANADIUM ALLOYS

Contract NOw 62-0101-c

Department of the Navy
Bureau of Naval Weapons
Washington 25, D. C.

Attention: Code RRMA-222

ARF-B231-8
(Bimonthly Report No. 8)

ARMOUR RESEARCH FOUNDATION
of
ILLINOIS INSTITUTE OF TECHNOLOGY
Technology Center
Chicago 16, Illinois

PILOT EVALUATION OF VANADIUM ALLOYS

Contract NOW 62-0101-c
ARF-B231-8
(Bimonthly Report No. 8)
November 18, 1962 - January 17, 1963

Department of the Navy
Bureau of Naval Weapons
Washington 25, D. C.
Attention: Code RRMA-222

February 11, 1963

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

PILOT EVALUATION OF VANADIUM ALLOYS

ABSTRACT

Experimental vanadium-columbium base alloys were fabricated to sheet from 200-gram arc-melted ingots. The composition V-60w/o Cb-1w/o Zr-0.075w/o C had ultimate tensile strength values of 97,000, 77,000, and 20,000 psi at 1800°, 2000°, and 2400°F, respectively. On a density-corrected basis, the values up to 2000°F were the highest of all materials studied under this and the preceding programs. The V-40w/o Cb-30w/o Ta-1w/o Hf alloy had higher 2400°F strength (25,400 psi) but lacked the high room-temperature ductility of the V-Cb-Zr-C material.

Extruded and wrought plate, and sheet stock from the second 100-pound ingot (nominal composition V-4w/o Ti-20w/o Cb-1w/o Zr-0.075w/o C) was received and distributed to organizations participating in the data-exchange program. A total of 44 pounds of usable material was obtained, compared to about 30 pounds for the first large ingot.

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

PILOT EVALUATION OF VANADIUM ALLOYS

I. INTRODUCTION

This is the eighth bimonthly report, covering progress made during the period November 18, 1962 to January 17, 1963, under Contract NOW 62-0101-c, entitled "Pilot Evaluation of Vanadium Alloys" (ARF Project B231). Previous studies of vanadium-columbium alloys have demonstrated the excellent workability, weldability, elevated-temperature strength, and coatability of compositions in this system. The current program is concerned with alloy development (the optimization of both vanadium- and columbium-rich alloys) and with the preparation of 100- or 150-pound ingots of the most promising compositions for pilot evaluation. The alloy development efforts, based on data obtained from 200-gram arc-melted ingots, are substantially complete. In addition, two of the 100-pound ingots have been extruded, fabricated to sheet, and are currently being evaluated at the Foundation and by aerospace and other organizations participating in the data-exchange program. Silicide-base coatings are currently under study under Contract N600(19)59182, and this related program includes the coating of vanadium alloy specimens prepared under the pilot evaluation programs. Another current program, under Contract N600(19)59567 is aimed at improving the stress-rupture properties of vanadium alloys by investigation of dispersion-strengthening mechanisms.

During the current reporting interval, efforts have been devoted to the evaluation of mechanical properties of experimental alloys, so that the composition of a third large ingot can be selected. Although these data are substantially complete, specimens of a number of these experimental alloys have been siliconized (ARF Program B6004) and are currently being exposed to 2200° F air. Final selection of a composition will be made as soon as the silicide coatings have demonstrated adequate protective capabilities up to at least 2400° F. Also, during this report period sheet, plate, and bar stock from the second 100-pound ingot (the composition V-4Ti-20Cb-1Zr-0.075C^{*})

^{*} Compositions are reported in weight per cent.

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

was received from Du Pont and subsequently forwarded to organizations desiring specimens for evaluation.

II. RESULTS AND DISCUSSION

A. Experimental Alloys--Fabrication

The previous bimonthly progress report included a list of the experimental alloys prepared under this program (Table I, ARF-B231-7). During the current report period, four additional 200-gram compositions were arc-melted. These included:

V-1Zr-60Cb-10Ta-0.075C

V-35Cr-1Zr

V-25Mo-2Zr-0.1C

V-25Mo-2.5Hf-0.1C

The first of these compositions was selected to study the effects of a 10w/o tantalum addition to a V-60Cb base complexed with zirconium and carbon. The remaining three alloys were selected on the basis of alloy development studies performed by Crucible Steel Company.⁽¹⁾ All ingots except the V-25Mo-2.5Hf-0.1C material fabricated to 0.050-inch thick sheet by hot rolling (2300°F) followed by warm (1200°F) then cold rolling. Specimens are being prepared for tensile and other evaluations.

Three additional ingots which were listed in Table I of the previous report (ARF-B231-7) were subsequently fabricated by hot- and cold-working techniques. These alloys were based on V-1Ti-70Cb, and contained 5w/o each of tungsten, tantalum, or molybdenum. Only the ingot containing 5w/o molybdenum could not be rendered to 0.050-inch thick sheet.

B. Experimental Alloys--Tensile Data

Tensile data for a number of compositions were obtained at room temperature, and at 1800°, 2000°, and 2400°F. These sheet specimens, 0.050-inch thick, were in the fully recrystallized condition, and a strain rate of 0.06 in./in./min was used. Elevated temperature data were

(1) V. C. Petersen and H. B. Bomberger, "Development of Improved Vanadium-Base Alloys for Elevated-Temperature Use," ASD-TDR-62-667, August, 1962

obtained under a highly purified helium atmosphere. The purity of the test atmosphere was checked by the use of contamination indicator tabs of D-31 sheet wired to the gage length of tensile specimens, and subsequently evaluated for microhardness. In addition, each elevated-temperature tensile sample was subjected to a room-temperature bend test in the gage portion after fracture. Bend ductility values compared favorably with results obtained on annealed sheet, indicating absence of excessive contamination during elevated-temperature testing.

The results of these tensile evaluations are presented in Table I. In some cases, data from earlier reports showing results at other test temperatures are also included. Nine of the compositions were vanadium-rich, containing approximately 67 to 75w/o of this element. The balance of the alloys contained from 24 to 39w/o of vanadium, with columbium contents ranging from 30 to 70w/o.

Data for the high-vanadium alloys included four compositions based on V-4Ti-1Zr. Carbon additions to this base resulted in an increase in the elevated-temperature strength properties, especially in combination with 5w/o tantalum and 2.5w/o molybdenum. A small ruthenium addition (0.5w/o) to the 20Cb-4Ti-1Zr base produced a material which appeared to be hot-short at 1800° and 2000°F. Somewhat higher strengths were noted for a V-20Cb-2.5Mo-1Zr-0.075C base containing 5w/o tantalum or tungsten. The highest strengths at 1800°F and above were found in alloys based on V-20Cb-1Zr-0.075C with additions of 10w/o tantalum or tungsten. The composition V-20Cb-10W-1Zr-0.075C had ultimate tensile-strength values of 72,500, 51,700, and 14,300 psi at 1800°, 2000°, and 2400°F, respectively. A subsequent table will compare the density-corrected strength values for experimental alloys. While the 10w/o tungsten and tantalum additions produced relatively high strengths, these elements greatly increase the density, and their effect on coatability has not yet been established. Another composition at the 20w/o columbium level, V-20Cb-10Ta, had unusually high 2400°F strength (15,400 psi), but had low tensile elongation (4 per cent) at room temperature.

Two alloys containing relatively large tantalum additions were evaluated. These compositions, V-30Cb-35Ta-1Hf and V-40Cb-30Ta-1Hf were among the strongest of all alloys studied under this and previous vanadium-alloy development programs. The latter composition had ultimate tensile strengths of 93,000, 69,500, and 25,400 psi at 1800°, 2000°, and 2400° F, respectively. While the density-corrected strength values at 1800° and 2000° F are slightly lower than values for several other alloys, the 2400° F strength-density ratio exceeds all other compositions tested. These two compositions have relatively low tensile elongations at 1800° F, and the room-temperature tensile elongation values (7 and 10 per cent) indicate slightly reduced ductility, compared to other alloys studied. The remaining alloys listed in Table I contain 60 and 70w/o columbium. Data are included for sheet specimens from the 100-pound V-1Ti-60Cb ingot, prepared by double consumable-electrode arc-melting, followed by extrusion, and rolling. This material had unusually high tensile elongation (25%) at room temperature; possibly a result of the relatively low interstitial content.

Four experimental alloys were based on V-1Ti-60Cb. Tensile data for these compositions are not complete, but two alloys had low room-temperature ductility: V-1Ti-60Cb-2.5Mo-0.5Ru with 1% tensile elongation and V-1Ti-60Cb-5Ta with 6% elongation. Addition of 0.1w/o carbon or 0.075w/o oxygen to V-1Ti-60Cb produced a moderate increase in the 2000° F strength, although the latter alloy was difficult to fabricate.

Three compositions based on V-1Hf-60Cb were also studied, and elevated-temperature data show that the addition of 10w/o tantalum produced considerable strengthening, especially at 2400° F. The remaining alloy at the 60w/o columbium level, V-60Cb-1Zr-0.075C, was the strongest composition studied under these programs at 1800° and 2000° F; the ultimate tensile strength values were 97,000 and 77,000 psi, relatively. At 2400° F this alloy has an ultimate strength of about 20,000 psi, the strongest of the more ductile 60w/o columbium alloys at this temperature. A new ingot of this composition is being prepared to recheck these values, and to obtain additional room-temperature data. Results for this alloy confirm earlier findings that zirconium in combination with carbon is an effective strengthener in vanadium-columbium alloys.

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

Experimental alloys evaluated during this reporting interval also include two compositions at the 70w/o columbium level, V-1Ti-70Cb-5Ta and V-1Ti-70Cb-5W. While both materials had relatively high-strength values at 2000° and 2400°F, their room-temperature ductility was excessively low--tensile elongations were 0 to 2 per cent. While their 2400°F strength values were near 20,000 psi, the density-corrected strengths do not compare favorably with other lower-columbium materials.

A group of selected alloys for which density-corrected strength values have been calculated is shown in Table II. These data are for compositions which could be readily fabricated to sheet; however, in a few cases, the room-temperature ductility may be somewhat low. Strength-density ratios at room-temperature vary over a relatively narrow range. Considerably larger variations occur at elevated temperatures, and the higher-columbium alloys usually exhibit higher strengths on a density-corrected basis. The composition exhibiting, by far, highest strength-density ratio at room temperature and at 1800° and 2000°F was V-60Cb-1Zr-0.075C, and this alloy at 2400°F was strongest except for the V-40Cb-30Ta-1Hf material. Although coatability of these compositions has not been established, it is anticipated that no difficulties will be encountered with pack-siliconized coatings on the V-60Cb-1Zr-0.075C alloy. Thus, this composition appears to be a logical candidate for the third large ingot for pilot evaluation.

C. Large Ingot Fabrication

Extruded and wrought stock from the second 100-pound ingot was received from Du Pont. The nominal composition of this material was V-4Ti-20Cb-1Zr-0.075C. Ingot analyses were reported in the previous bi-monthly progress report (ARF-B231-7). Since that time, several sections of the 0.050-inch thick sheet have been analyzed for carbon, with results ranging from 0.05 to 0.07w/o carbon (0.06w/o average). These data confirm the earlier analyses, and indicate that some carbon was lost during melting.

After fabrication, approximately 15.8 sq ft of 0.050-inch thick sheet, 2.1 sq ft of 0.125-inch plate, 0.21 sq ft of 0.5-inch plate, and a 3 1/2 by 6 1/2 by 1 in. section of as-extruded bar were available for evaluation. Figure 1 is a photograph of this material, showing the relatively small amount of edge cracking on the thin sheets. A total of 44 pounds of excellent quality stock was received, and the ingot, prior to extrusion, weighed approximately 65 pounds. This yield is considerably better than that obtained for the first 100-pound ingot, which yielded only about 30 pounds of usable material. Du Pont commented that this high-vanadium ingot did not work-harden to the degree experienced with the V-1Ti-60Cb alloy, and only one intermediate anneal was required in sheet rolling of the V-4Ti-20Cb-1Zr-0.075C material.

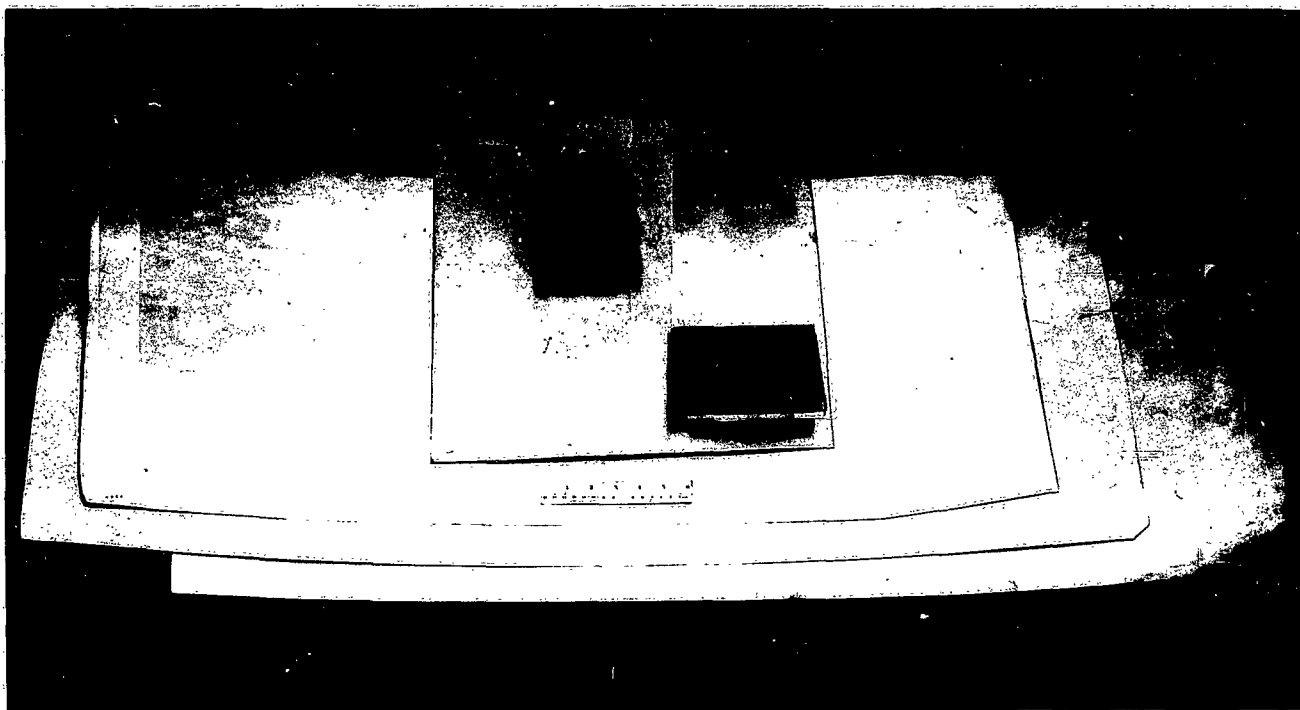
Sheet and other stock from this second large ingot were forwarded to the organizations requesting material for evaluation under the data-exchange portion of this program. A complete list of materials forwarded will be included in a subsequent report. In addition, a portion of the plate and sheet stock was retained by the Foundation for detailed mechanical property evaluations. These data will be presented in tabular form as soon as the various phases of the evaluations have been completed. Some data are now available for the first 100-pound ingot (V-1Ti-60Cb), and these results will be presented in a subsequent report when additional data are obtained.

Arrangements have been made to have tensile and stress-rupture tests conducted at Watertown Arsenal (AMRA), on sheet material from the second and third large ingots. Two square feet of the second ingot (V-4Ti-20Cb-1Zr-0.075C) are currently being annealed and will be forwarded to Watertown in the near future. Selection of a composition for the third ingot will be made as soon as the silicide coatings have been evaluated on some of the more promising alloys.

III. SUMMARY

Experimental vanadium alloys, prepared as 200-gram nonconsumable-electrode arc-melted ingots, were evaluated for tensile properties at temperatures up to 1200° F. On a density-corrected basis, the alloy

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY



Neg. No. 24132

Fig. 1

Bar, plate, and sheet stock from the 100-pound ingot of V-4Ti-20Cb-1Zr-0.075C. Very little edge cracking occurred on the large 0.050-inch thick sheets.

V-60Cb-1Zr-0.075C was the strongest of all highly-ductile compositions tested to date at room temperature and at 1800° and 2000° F. Its density-corrected strength at 2400° F was among the highest of all materials studied under this and previous programs. A high-tantalum composition, V-40Cb-30Ta-1Hf, exhibited a slightly higher strength-to-density ratio at 2400° F, but this material had low room-temperature tensile elongation (7 per cent) compared to the 15 per cent value for the V-Cb-Zr-C material. A number of alloys containing 20w/o vanadium with additions of reactive elements (titanium and zirconium), refractory metals (molybdenum, tantalum, and tungsten), and carbon, were evaluated at temperatures up to 2400° F. These materials, generally, had higher room-temperature elongations but were weaker on a density-corrected basis than the high-columbium alloys at all temperatures.

Based on results to date, the V-60Cb-1Zr-0.075C composition is the most logical selection for the third large ingot for pilot evaluation. The behavior of pack-siliconized coatings and weldability and bend ductility of this alloy are currently being investigated prior to issuing a purchase order for melting of the large ingot.

Extruded bar and wrought plate and sheet stock from the second 100-pound ingot (V-4Ti-20Cb-1Zr-0.075C) were received. A total of 44 pounds of excellent quality stock was obtained, compared to a yield of only about 30 pounds for the first ingot. Samples have been forwarded to aerospace and other organizations participating in the data-exchange program. Arrangements have also been made to have sheet stock from the second and third large ingots evaluated at Watertown Arsenal (AMRA).

IV. FUTURE WORK

The alloy development phase of this program has been completed except for a limited number of mechanical property evaluations on compositions currently in process. Selection of a composition for the third large ingot will be made as soon as tensile values of the most promising materials are rechecked, and the protective capabilities of silicide coatings on these alloys have been demonstrated. Sheet and plate stock from the first two

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

100-pound ingots are currently being evaluated for mechanical and other properties at the Foundation, and also at aerospace and other organizations who have been supplied with materials. Data from these evaluations will be presented in subsequent bimonthly reports, and will be summarized in a Final Report when all information has been received from the other organizations.

V. CONTRIBUTING PERSONNEL AND LOGBOOKS

The following personnel contributed to the work reported herein:

F. C. Holtz	-	Project Supervisor
B. R. Rajala	-	Project Leader
L. B. Richard	-	Project Technician
R. J. Van Thyne	-	Advisor

Respectfully submitted,

ARMOUR RESEARCH FOUNDATION OF
ILLINOIS INSTITUTE OF TECHNOLOGY



F. C. Holtz
Senior Metallurgist
Metals and Ceramics Research

FCH/rh

Tech Rev - CRS

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

TABLE I

TENSILE PROPERTIES OF FULLY ANNEALED VANADIUM-BASE ALLOYS

(All tests conducted at 0.06 in./in. /min strain rate)

Composition, w/o	Room Temperature			1800° F			2000° F			2400° F		
	UTS, 1000 psi	YS, 1000 psi	Elong., %	UTS, 1000 psi	YS, 1000 psi	Elong., %	UTS, 1000 psi	YS, 1000 psi	Elong., %	UTS, 1000 psi	YS, 1000 psi	Elong., %
20Cb-4Ti-1Zr- 0.05C				45.0	41	26	29.5		88	12.1	11.4	120
20Cb-4Ti-1Zr- 0.075C	113.4	102.9	14	56.2	54	27	39.4	35	112	12.3	11.9	118
20Cb-4Ti-1Zr- 0.05Ru	112.0	100.0	23	56.0	52	14 ^a	33.5	32	19 ^a	12.8	10.9	93
20Cb-4Ti-1Zr-5Ta- 2.5Mo-0.075C	120.0	106.0	24	65.5	62	19	43.0	39	45	10.1	9.6	93
20Cb-5Ta-2.5Mo- 1Zr-0.075C	130.0	116.0	26				51 50	44 47	91 76	13.4	12.5	141
20Cb-5W-2.5Mo- 1Zr-0.075C	130.0	116.5		65.0	59	24	44.0	42	36	13.0	12.2	128
20Cb-10Ta	129.1	124.6	4	60.7	51	12	45.4	40	34	15.4		86
20Cb-10Ta-1Zr- 0.075C	117.5	102	16	65.0	58	15	49.0	47.5	46	13.9	11.1	141
20Cb-10W-1Zr- 0.075C	128.5	115	23	72.5	65	16	51.7	49	60	14.3	13.2	127
30Cb-35Ta-1Hf	160.0	148.5	10	91.7	84.5	9	70.2	66	14	20.9	18.7	117
40Cb-30Ta-1Hf	155.0	142	7	93.0	84	7	69.5	65	26	25.4	22.4	124
60Cb-1Ti	145.0	129.0	25 ^b	73.0	63	23 ^b	60.0	55	43	13.6		60

TABLE I (continued)

Composition, w/o	Room Temperature			1800° F			2000° F			2400° F		
	UTS, 1000 psi	YS, 1000 psi	Elong. %	UTS, 1000 psi	YS, 1000 psi	Elong. %	UTS, 1000 psi	YS, 1000 psi	Elong., %	UTS, 1000 psi	YS, 1000 psi	Elong., %
60Cb-1Ti-0.1C							63.0	56	67			
60Cb-1Ti-0.075O							65.0	59	65			
60Cb-1Ti-2.5Mo- 0.5Ru	159.0	158.7	1				65.5	59	31	19.0 21.3	18.6 20.3	72 40
60Cb-1Ti-5Ta	152.4	150.1	6				59.0	51	55			
60Cb-1Hf				79.0	71	21	63.0	59		12.8		75
60Cb-1Hf-5W							50.5	46	68			
60Cb-1Hf-10Ta							63.8	57.7	40	19.6	19.0	106
60Cb-1Zr-0.075C	161.5	144	15	97.0	91	12	77.0	72.0	19	17.1 20.2	13.2 19.0	151 170
70Cb-1Ti-5Ta	157.0	156.4	2				71.2	67	24	18.7	16.5	75
70Cb-1Ti-5W	160.1		0				66.8	60.3	40	20.1	18.5	67

a. Numerous cracks in gage section.

b. Data for 100-pound ingot.

TABLE II
DENSITY-CORRECTED STRENGTH VALUES
FOR VANADIUM-BASE ALLOYS

Composition, w/o	Density lb/in. ³	Ultimate Tensile Strength/Density, 1000 psi/(lb/in. ³)		
		R. T.	1800° F	2000° F
20Cb-5Ti	.229	490	153	38.4
20Cb-4Ti-1Zr-0.075C	.230	490	244	53.5
20Cb-4Ti-1Zr-5Ta-2.5Mo-0.075C	.240	500	273	42.1
20Cb-5Ta-2.5Mo-1Zr-0.075C	.244	532	209	55.0
20Cb-5W-2.5Mo-1Zr-0.075C	.245	530	266	54.7
20Cb-10Ta	.250	517	243	61.6
20Cb-10Ta-1Zr-0.075C	.250	470	260	55.6
20Cb-10W-1Zr-0.075C	.252	514	290	57.1
30Cb-35Ta-1Hf	.320	500	287	65.3
40Cb-30Ta-1Hf	.319	485	291	79.6
60Cb-1Ti	.265	547	276	51.3
60Cb-1Ti-5Ta	.276	553	214	
60Cb-1Hf	.268		295	59.7
60Cb-1Hf-10Ta	.291		220	67.5
60Cb-1Zr-0.075C	.267	605	363	75.5

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

DISTRIBUTION LIST

Contract NOW 62-0101-c

Commander
Aeronautical Systems Division
Wright-Patterson Air Force Base
Ohio
Attn: ASRCMP-1

Nuclear Metals Incorporated
Concord, Massachusetts
Attn: Dr. A. Kaufmann

Battelle Memorial Institute
505 King Avenue
Defense Metals Information Center
Columbus 1, Ohio

University of California
Lawrence Radiation Laboratory
Post Office Box 808
Livermore, California
Attn: Mr. Clovis G. Craig
Technical Information Div.

Lockheed Aircraft Corporation
Lockheed Missiles Systems Div.
Hanover Street
Palo Alto, California
Attn: Dr. T. E. Tietz

Commander
Air Force Ballistic Missile Div.
5760 Arbor Vitae Street
Inglewood 45, California
Attn: WDTLA

Commander
Watertown Arsenal
Watertown 72, Massachusetts
Attn: Mr. S. Arnold

Commander
Ordnance Corps., Frankford Arsenal
Pitmann Dunn Laboratory
Philadelphia 37, Pennsylvania

Chief of Naval Research (ONR:423)
Department of the Navy
Washington 25, D. C.

Director
U. S. Naval Research Laboratory
Metallurgy Division
Washington, D. C.
Attn: Mr. W. Pellini

U. S. Atomic Energy Commission
Division of Reactor Development
Engineering Development Branch
Washington 25, D. C.
Attn: Mr. J. M. Simmons
Chief, Metallurgy

Department of the Navy
Bureau of Ships
Washington 25, D. C.
Attn: Code 343

Boeing Airplane Company
Seattle, Washington
Attn: Mr. E. C. Bovee
Staff Engineer for Materials
and Processes Staff

Republic Aviation Corporation
Farmingdale, Long Island, New York
Attn: Dr. S. Karman
Chief, Materials Development
Division

U. S. Atomic Energy Commission
Technical Information Service
Post Office Box 62
Oak Ridge, Tennessee

Commanding Officer
Naval Air Material Center
Aeronautical Materials Laboratory
Philadelphia Naval Base
Philadelphia 12, Pennsylvania

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

National Aeronautics and Space
Administration
1520 H Street, N. W.
Washington 25, D. C. (3 copies)

National Academy of Sciences
Materials Advisory Board
2101 Constitution Avenue, N. W.
Washington 25, D. C.
Attn: Dr. Joseph Lane

Oregon Metallurgical Corp.
Post Office Box 484
Albany, Oregon
Attn: Mr. Russell G. Hardy

General Electric Company
Aircraft Nuclear Propulsion Dept.
Cincinnati, Ohio
Attn: Mr. James McGurty

National Aeronautics and Space
Administration
Lewis Research Center
21000 Brookpark Road
Cleveland 35, Ohio
Attn: Mr. Charles A. Barrett

Aerojet-General Nucleonics
San Ramon, California
Attn: Mr. Irwin Rhen

Storchheim Research and
Development Corp.
34-32 57th Street
Woodside, New York
Attn: Mr. Samuel Storchheim

E. I. du Pont de Nemours and
Company, Inc.
Wilmington 98, Delaware
Attn: Mr. J. Symonds
Pigments Department

Crucible Steel Company of America
Mellon Square
Pittsburgh 22, Pennsylvania
Attn: Mr. Walter L. Finlay

Union Carbide Metals Company
4625 Royal Avenue
Post Office Box 580
Niagara Falls, New York

Battelle Memorial Institute
Columbus 1, Ohio
Attn: Mr. H. R. Ogden

General Electric Company
Flight Propulsion Laboratory
Cincinnati 15, Ohio
Attn: Mr. R. G. Frank, Manager
Space Metallurgy Projects
ARO Building 200

Chromalloy Corporation
169 Western Highway
West Nyack, New York
Attn: Mr. Richard L. Wachtell

Harvey Aluminum
Research and Development Div.
19200 South Western Avenue
Torrance, California

Haynes Stellite Company
Division of Union Carbide Corp.
Kokomo, Indiana
Attn: Mr. H. F. Kuhns

U. S. Bureau of Mines
Boulder City Metallurgy Research
Laboratory
Boulder City, Nevada
Attn: Dr. D. H. Baker, Jr.

Armed Services Technical
Information Agency
Arlington Hall Station
Arlington 12, Virginia (5 copies)

Department of the Navy
Bureau of Naval Weapons
Washington 25, D. C.
Attn: Mr. Richard Schmidt
Code RRMA-222

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

Office of Naval Research
86 East Randolph Street
Chicago 1, Illinois
Attn: Mr. R. Hedlund (3 copies +
repro)

SYLCOR Division
Sylvania Electric Products Inc.
208-20 Willets Point Blvd.
Bayside, Long Island, New York
Attn: Mr. L. Sama
Section Head, Metallurgy Dept.

National Aeronautics and Space
Administration
Langley Research Center
Langley Station
Hampton, Virginia
Attn: Mr. Charles Manning

Mc-Donnell Aircraft Corporation
Lambert-Sain Louis Municipal
Airport
Post Office Box 516
St. Louis 66, Missouri
Attn: Mr. Howard Siegel
Dept. 272

Bell Aerosystems Company
Division Bell Aerospace
Corporation
Buffalo 5, New York
Attn: Mr. E. A. Dalega

North American Aviation, Inc.
Rocketdyne Division
6633 Canoga Avenue
Canoga Park, California
Attn: Mr. R. J. Thompson, Jr.
Director Research

North America Aviation, Inc.
Los Angeles Division
International Airport
Los Angeles 9, California
Attn: Mr. H. H. Crotaley
Manager, Applied Science

Chance-Vought Corporation
Astronautics Division
Post Office Box 6267
Dallas 22, Texas
Attn: Mr. M. J. Rudick
Mgr., Space Technology

Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base,
Ohio
Attn: Mr. James J. Mattice
Acting Chief, Coatings Section
Nonmetallic Materials
Laboratory
Directorate of Materials
and Processes

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY